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Ten years trends in the oligochaete and chironomid fauna of Lake Neuchâtel (Switzerland)

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Ten years trends in the oligochaete and chironomid fauna of Lake Neuchâtel (Switzerland). - Quantitative surveys of benthic macroinvertebrates (oligochaetes and chironomids) were conducted during 1992, 1997, 2000 and 2002 at a depth of 40 m to monitor the biological quality of sediments in Lake Neuchâtel. Recent declines in frequency of occurrence and abundance of oligochaete species characteristic of oligotrophic conditions (*Stylodrilus heringianus*, *Embolocephalus velutinus*) contrasted with the improvement of water quality metrics. Total phosphorus concentrations in lake waters decreased from 63 mg m^{-3} in 1980 to 10 mg m^{-3} in 2002. Since 1992, significant reductions of total zoobenthic biomass have been recorded and the chironomid community structure reflects typical oligo-mesotrophic conditions in the upper sediment layer. The population of the oligochaete species *Potamothrix vejdovskyi* is in clear expansion and indicates that this new species for the lake (1986) has found good conditions for a successful colonization. These divergent responses within the zoobenthic community are discussed according to three main hypotheses: implications of toxic pollutants like heavy metals and organic micropollutants in the sediment, impact of algae on oxygen conditions on the bottom layer and different biological responses of oligochaetes to competition for food and space.

Keywords: Zoobenthos - biomonitoring - profundal zone - sediment contamination - organic deposition - micropollutant.

INTRODUCTION

In marine and lacustrine ecosystems, it is generally accepted that pelagic phytodetrital organic material, derived from autochtonous and allochthonous inputs, drives profundal zoobenthos production (Brinkhurst, 1974; Graf, 1989). The major part of autochtonous input arises from phytoplankton primary production which is controlled largely by nutrient elements (mainly P and N) coming in the system (Håkanson & Jansson, 1983). Thus, profundal macroinvertebrate growth is supported directly by nutrients in fresh or decaying algae or indirectly via microbial production (Johnson & Wiederholm, 1992).

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The deep bottom fauna of lakes is dominated by oligochaete worms and chironomid larvae. Additional invertebrates are molluscs, crustaceans, watermites, flatworms and minor insect taxa which usually occur in rather limited numbers (Wiederholm, 1980). The two main taxa have different biological traits: chironomid larvae have a surface deposit-feeding strategy, which show many diets (algae and freshly deposited detritus, sediment bacteria and invertebrates), whereas oligochaete are subsurface deposit-feeders (mainly bacterial food and organic matter). Their reproductive behavior is also distinctive: oligochaetes reproduce within the sediment whereas chironomids have aerial stages and oviposit on the water surface (Johnson & Wiederholm, 1992; Goedkoop & Johnson, 1993). Therefore, they do not respond equally to environmental changes. Under conditions of recovery, oligochaetes seem to maintain their community structure for a longer time than chironomids (Wiederholm, 1980; Lang, 1998).

In Lake Neuchâtel, despite decreasing phosphorus concentration since the 1980s, densities of oligochaete species intolerant of oxygen depletion and organic deposition tended to decrease after 1992 (Lang 1999, 2001). To examine this trend, the same biomonitoring survey as in 1992, 1997 and 2000 was performed in 2002 in order to monitor the zoobenthic assemblages and further investigations were carried out on potential toxic contaminants of lake sediments. The present study focuses also on the change of the zoobenthic communities during the last ten years.

STUDY AREA, SITES AND METHODS

STUDY AREA

Lake Neuchâtel, located at the southern foot of the Jura Mountains, is one of the largest Swiss lakes with a surface area of 215 km^2. Its orientation is parallel to the major wind directions, resulting in a good oxygen supply even to the deepest waters. Oxygen concentrations one meter above bottom sediment have always been above 7 mg L^{-1} from 1982 to 2002 (Pokorni-Aebi, 2002). Six major tributaries discharge into both ends of the lake (Fig 1). The main characteristics of the lake are given in Table 1. In 2002, physico-chemical and phytoplanktonic features classified this lake as mesotrophic (Håkanson, 1980).

SAMPLING SITES

In 2002, 30 sites were sampled along the southeasthern shore of Lake Neuchâtel (Fig. 1), between the villages of Portalban and Font. This biomonitoring transect is located along the largest fringing wetland in Switzerland (The "Grand Cariçaie" reserve), which is an almost 40 km-long continuous marshland belt. The sites, distributed evenly (500 m apart), were sampled six times in May, before the mass emergence of chironomids. At each site, six cores (16 cm^2, 30 cm long) were taken with a gravity corer lowered from the water surface.

Similar biomonitoring surveys were previously undertaken in 1992, 1997 and 2000 respectively by Lang & Reymond (1993) and Lang (1999, 2001). In 1984, 16 sampling sites were distributed along four transects, regularly spaced (4 km apart) in the same area. Along each transect, samples were collected at 40, 60, 90 and 120 m deep.

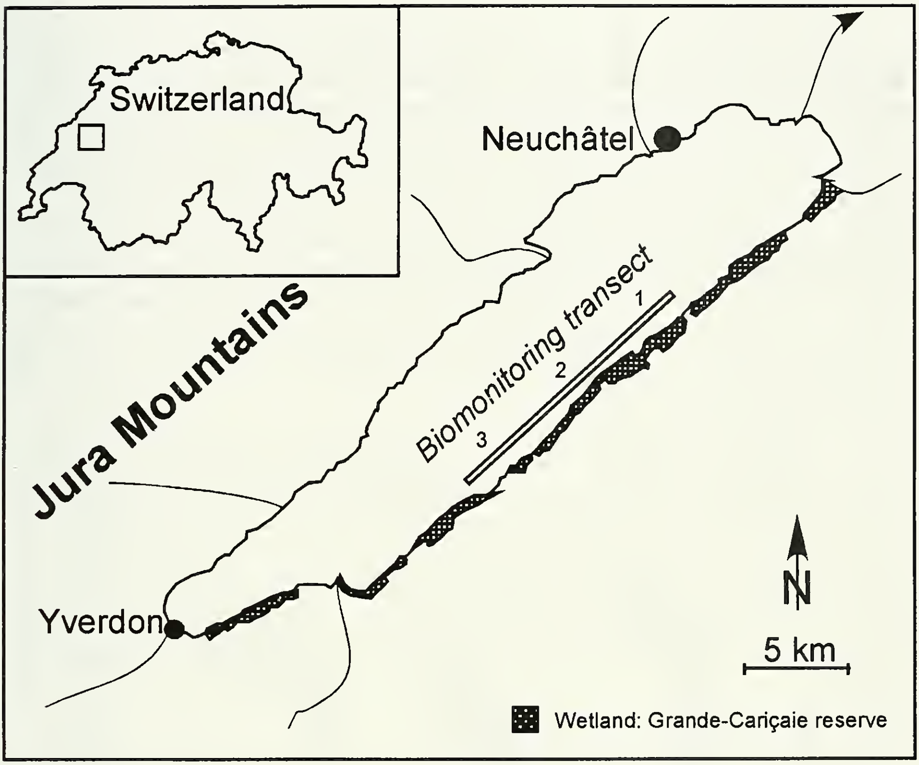


FIG. 1

Lake Neuchâtel showing inflows, outflow and sampling sites divided into 3 zones.

TABLE 1. Main characteristics of Lake Neuchâtel (Lang, 1996; Pokorni-Aebi, 2002)

Depth (m)	Mean	64
	Max	153
Lake surface area (km^2)		215
Volume (km^3)		13.8
Altitude of lake surface (m a.s.l.)		429
Area of drainage basin (km^2)		2672
Average altitude of the basin		780
No. of total circulation per year		2
Theoretical residence time (year)		8.2
Total phosphorus (mg m^{-3})[a]	1980	63.0
	2002	10.0
Secchi disc transparency (m)	2002	2.5-9.0
Mean algal biomass (0-20 m)(g m^{-3})	2002	1.26
Chlorophyll-a (0-20 m)(mg m^{-3})	2002	2.2-6.5

[a] Mean value for the spring circulation

Three zones on the 2002 transect were differenciated along a gradient of organic sedimentation (Lang, 2001).

CORE INVESTIGATIONS

From 1997, each sediment core was described in the laboratory according to thickness of three main vertical layers: i) the thin brownish surface layer of oxydized sediment, ii) the intermediate reduced black layer, which can be considered as a descriptor of organic deposition and matches with the 1940s to 1950s (Steinmann *et al.*, 2003) and iii) the compact grey or brown clay found underneath. After measurement of the thickness of the reduced black layer to the nearest 0.5 cm, each core sediment was sieved (mesh size 0.2 mm) and retained material preserved in 5% formalin. Collected macrofauna consisted mainly of lumbriculids, tubificids and chironomids which were sorted out and counted under a low magnification (6x) binocular microscope. Oligochaetes and chironomids were then mounted (Reymond, 1994) and identified to species or groups of species according to Brinkhurst (1971), and Wiederholm (1983, 1986).

Some species of lumbriculids and tubificids are known to be sensitive to oxygen depletion and organic deposition (Jónasson, 1969; Milbrink, 1978, 1980; Lang, 1990), and can be considered as bioindicators of oligotrophic conditions. The bioindicative value of species or species groups for chironomid larvae was based on Saether (1979). In 1984 and 1992, chironomids were counted separetely in each core, but they were identified only as a whole sample based on 64 and 171 cores, respectively. In 1997, 2000 and 2002, chironomids were counted and identified separetely in each core. Chironomid material prior to 2002 was re-examined and identified to species or groups of species.

CHEMICAL ANALYSES

In 2003, three composite samples were collected along the same transect including the upper 5 cm of sediment which represent approximately twenty years of sedimentation (Steinmann *et al.*, 2003). Chemical analyses were then performed on heavy metals (Cd, Cu, Cr, Ni, Pb and Zn) using Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP-AES). PCBs were determined by GC/MS after purification. Seven congeners were included (No. 28, 52, 101, 118, 138, 153, 180). PAHs (PolyAromatic Hydrocarbons) were determined by HPLC coupled with a fluorescence detector. They include Fluoranthene, Benzo(b)Fluoranthene, Benzo(k)Fluoranthene, Benzo(a)Pyrene, Benzo(g,h,i)Perylene, Indeno(1,2,3-cd)Pyrene.

STATISTICAL ANALYSES

Frequency of occurrence was calculated as the number of samples containing a particular species divided by the total number of samples. Relative abundance was the total number of individuals of a particular species collected in all samples in one particular year divided by the total number of oligochaetes or chironomids. Differences between years or zones for sediment parameters were tested with a one-way ANOVA. Kruskall-Wallis rank tests were used to test differences in zoobenthic abundance and biomass. All analyses and graphical displays were undertaken using SPSS software (10.1) for Windows.

RESULTS

Sediment condition and contamination

The thickness of the reduced black layer of soft sediment decreased significantly in 2002 along a eastern-western gradient (zone 1 to 3) ($F = 30.80$, $P < 0.0001$). Similar trends occurred in 1997 and 2000 ($F = 7.99$ and 38.24 respectively, $P < 0.0001$) (Fig. 2).

Micropollutant analyses of heavy metals, PCBs and PAHs in bottom sediments showed similar results in the three zones defined above (Table 2). Few values for PCBs and PAHs were above the quantitation limits of the methods. Fluorantene had the most elevated concentration (0.274 mg Kg^{-1} in zone 3).

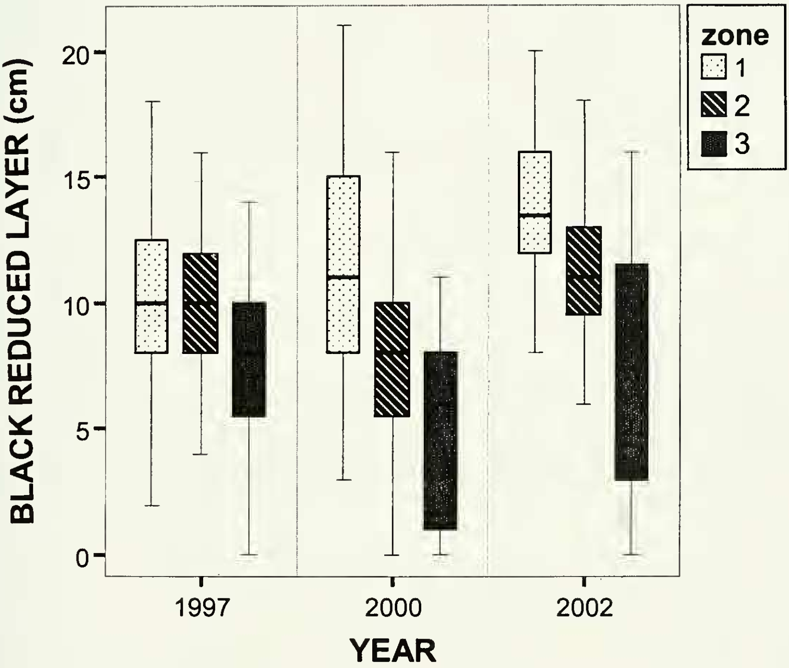


Fig. 2

Gradient of organic deposition, expressed as the thickness of the dark reduced layer between 1997 and 2002 and between zones. The median, percentiles (25th and 75th) and 1.5 interquartile range are indicated.

Table 2. Chemical characteristics of superficial sediments in the three zones of Lake Neuchâtel. All values are expressed as mg Kg^{-1} on a dry sediment weight basis. REF: reference values

Zone	Cd	Cr	Cu	Ni	Pb	Zn	Σ7PCB	Σ6 HAP
1	0.220	12.3	13.6	12.6	10.7	26.8	< 0.139	< 1.092
2	0.264	12.4	13.1	12.6	11.1	29.4	< 0.105	< 1.111
3	0.265	14.1	14.2	14.6	12.5	33.2	< 0.105	< 1.159
								Σ16 HAP
REF	0.2^1		30^1		30^1	60^1	0.1^2	1.0^2

^{1} : reference values (Vernet & Viel, 1984); ^{2} : reference values (Osol, 1998)

TABLE 3. Presence, frequency of occurrence and abundance (± SD) of oligochaete and chironomid fauna collected in the Lake Neuchâtel.

		Frequency of occurrence (%)						Abundance (No.m^{-2})					
		1918	1984	1992	1997	2000	2002	1992	1997	2000	2002	F	*P*
	OLIGOCHAETA												
o	*Bichaeta sanguinea* Bretscher	*	37.5	20.5	12.6	27.2	12.8	157 ± 26	82 ± 17	205 ± 30	94 ± 20	5.82	*0.001*
o	*Stylodrilus heringianus* Claparède	*		26.3	4.0	1.1	1.1	398 ± 51	25 ± 9	7 ± 5	7 ± 5	55.53	*< 0.001*
o	*Spirosperma velutinus* (Grube)	*	17.2	19.3	11.4	11.7	8.4	164 ± 30	82 ± 18	76 ± 16	62 ± 16	4.92	*0.002*
o	*Spirosperma ferox* (Eiscn)	*	1.6	13.5	19.4	20.0	13.9	102 ± 22	129 ± 20	153 ± 26	104 ± 21	1.11	*0.343*
	Potamothrix vejdovskyi (Hrabe)		0	23.4	42.9	51.1	67.2	259 ± 47	696 ± 84	1118 ± 118	1281 ± 128	20.41	*< 0.001*
	Limnodrilus hoffmeisteri (Claparède)	*	40.6	28.1	49.1	64.4	75.0	288 ± 49	660 ± 79	930 ± 81	139 5 ± 153	21.88	*< 0.001*
	Limnodrilus profundicola (Verrill)	*											
	Limnodrilus (juveniles)												
	Potamothrix hammoniensis (Michaelsen)	*	100	67.3	62.0	68.3	48.3	895 ± 74	821 ± 76	875 ± 72	580 ± 63	4.20	*0.006*
	Tubifex tubifex (Müller)	*											
	Branchiura sowerbyi (Beddard)						*				*		
	Potamothrix moldaviensis (Vcjdovsky & Mrazek)			*	*		*	*	*		*		
	Psammoryctides barbatus (Grube)	*				*	*			*	*		
	CHIRONOMIDAE												
o	*Macropelopia fehlmanni* (Kieffer)		*	*	0.1	2.2	3.3	63 ± 67	21 ± 9	14 ± 7	21 ± 8	0.18	*0.907*
o	*Paracladopelma nigritula* gr.			*	7.4	12.8	21.7	375 ± 170	46 ± 12	87 ± 18	160 ± 25	6.06	*< 0.001*
o	*Micropsectra notescens* gr.		*	*	71.4	26.7	52.9	128 ± 106	1164 ± 126	236 ± 37	691 ± 72	19.4	*< 0.001*
	Procladius (H.) spp.		*	*	24.0	14.4	38.3	267 ± 121	175 ± 26	90 ± 16	309 ± 40	9.8	*< 0.001*
	Sergentia coracina (Zcttersdedt)		*	*	6.3	18.9	0.0	17 ± 20	39 ± 11	132 ± 21	0	15.7	*< 0.001*
	Cryptochironomus spp.		*			*	*			*	*		
	Dicrotendipes spp.				*				*				
	Microtendipes chloris (Mcigen)						*				*		
	Polypedilum nubeculosum gr.			*	*		*	*	*		*		
	Tanytarsus spp.				*	*	*		*	*	*		
	No. of cores		*64*	*171*	*175*	*180*	*180*	*171*	*175*	*180*	*180*		

* : presence of the taxa; o : indicator of oligotrophic conditions

EVOLUTION OF ZOOBENTHIC COMMUNITIES

In 2002, zoobenthos (Table 3) consisted mainly of lumbriculid and tubificid worms (12 species) and chironomid larvae (8 taxa). The main oligochaete taxa were present at each biomonitoring survey. *Branchuira sowerbyi, Potamothrix moldaviensis* and *Potamothrix vejdovskyi* were recent for the lake and the latter is a new colonist since 1986 (Lang & Reymond, 1993).

For two of the four oligochaete species bioindicators of oligotrophic conditions (*Stylodrilus heringianus* and *Embolocephalus velutinus*), frequency of occurence and relative abundance tended to decrease through years with a strong shift after 1992 (Fig. 3A), whereas for *Bichaeata sanguinea* and *Spirosperma ferox*, no characteristic trends were seen (Fig. 3A and 3B, Table 3). Concerning the non-oligotrophic type worms, *Potamothrix vejdovskyi* showed a significant pattern, expanding spatially (present in 67% of the sites in 2002) and numerically (its population was five times higher in 2002 than in 1992) in no more than ten years (Kruskall-Wallis rank test, $k = 76.13$, $p < 0.05$) (Table 3 and Fig 3B). Populations of *Potamothrix hammoniensis* and *Tubifex tubifex* were started to decrease (Kruskall-Wallis rank test, $k = 18.10$, $p < 0.05$). In contrast, *Limnodrilus* species showed an inverse trend (Kruskall-Wallis rank test, $k = 101.28$, $p < 0.05$).

The chironomid community was dominated by three taxa bioindicators of oligotrophic conditions, *Macropelopia fehlmanni*, *Paracladopelma nigritula* gr. and *Micropsectra notescens* gr. which occurred in 42-78% of the samples (Fig 3C), depending on years. The presence of *Micropsectra contracta* (*notescens* gr.) was confirmed by pupal examination. *Procladius*, a rather euryecious and predatory genus was the fourth dominant taxon in terms of frequency of occurrence and abundance.

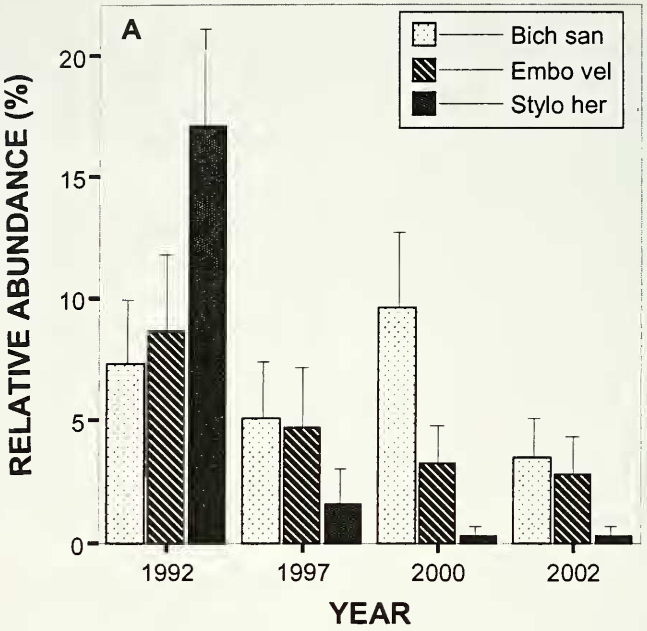
Total mean zoobenthic biomass (oligochaete and chironomid larvae) decreased significantly between 1992 and 2002 (Kruskall-Wallis rank test, $k = 50.67$, $p < 0.05$) and also between the three zones (Fig 4, Table 4) following the same east-west gradient of organic deposition.

Mean total abundance of worms (Fig 5) increased significantly through years (Kruskall-Wallis rank test, $k = 58.72$, $p < 0.05$); *Potamothrix vejdovskyi* and *Limnodrilus* were mainly responsible for this change. The major augmentation in oligochaetes occurred between 1997 and 2000. Chironomid assemblages showed an up-and-down pattern in their total abundance, mainly reflecting variations in *Micropsectra* density (Kruskall-Wallis rank test, $k = 52.10$, $p < 0.05$).

DISCUSSION

DIVERGENT TRENDS AT THE ZOOBENTHIC COMMUNITY LEVEL

The zoobenthic communities reflected different trends with regard to the time-scale and the type of organism considered. Despite a phase of eutrophication during the 1970s, oligochaete assemblages retained their native composition since the beginning of the XXth century (Monard, 1919). Three new species of oligochaetes, from the Ponto-Caspian area, appeared in the lake during the last century (*Potamothrix moldaviensis, P. vejdovskyi* and *Branchiura sowerbyi* (Brinkhurst & Jamieson, 1971; Lang, 1984; Lang & Reymond, 1993). In 1918, *Embolocephalus velutinus* was the most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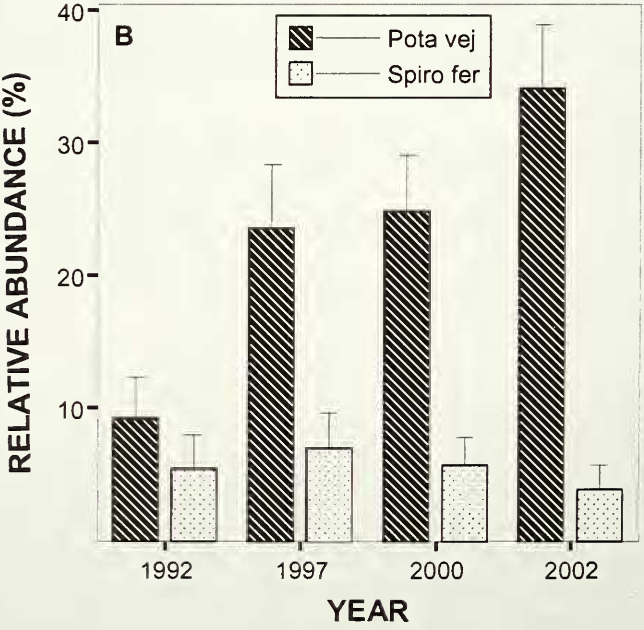
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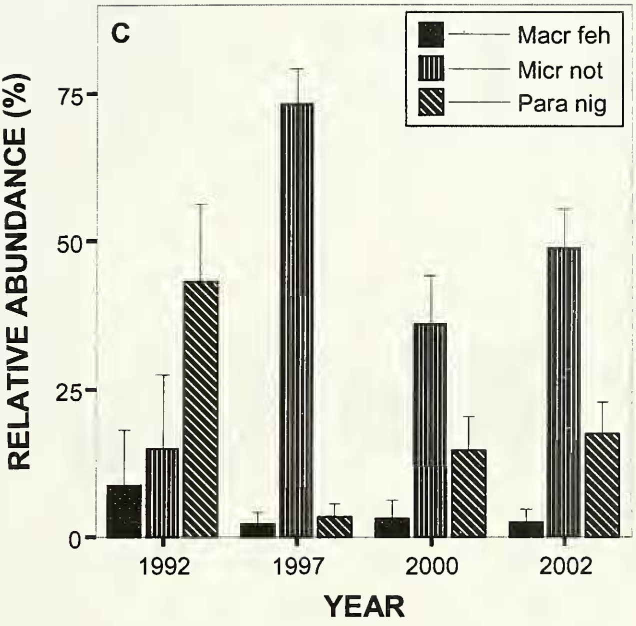

FIG. 3

Relative abundance of species (± CL) between 1992 and 2002. A: 3 oligochaete species indicators of oligotrophic conditions (Bich san: *Bichaeta sanguinea*; Embo vel: *Embolocephalus velutinus*; Styl her: *Stylodrilus heringianus*); B: more tolerant oligochaete species to oxygen depletion and organic deposition: Pota vej: *Potamothrix vejdovskyi* and Spir fer: *Spirosperma ferox*; C: chironomid taxa (Macr feh: *Macropelopia fehlmanni*; Micr not: *Micropsectra notescens* gr.; Para nig: *Paracladopelma nigritula* gr.).

frequent species followed by *Potamothrix hammoniensis*, *Stylodrilus heringianus* and *Tubifex tubifex* (Monard, 1919). Since 1984, oligochaete fauna has been dominated by the more tolerant taxa *Potamothrix hammoniensis* and *Tubifex tubifex* in terms of frequency and abundance. After 1992, a strong reduction in density of two species intolerant to oxygen depletion and/or organic deposition (Brinkhurst, 1964; Milbrink, 1978, 1983) was noted (*Stylodrilus heringianus* and *Embolocephalus velutinus*). The dominating position of *Tubifex tubifex* at both ends of the trophic scale would seem to be rather controversial (Milbrink, 1978, 1980). As is now widely recognized, at low organic content, *T. tubifex* is generally a dominating species together with *Stylodrilus* and *Embolocephalus* species and abundances remains low (Milbrink, 1978; Milbrink *et al.*, 2002). This was the case in the beginning of the XXth century in Lake Neuchâtel. The persistance in 2002, of a low density of *Stylodrilus heringianus* and *Embolocephalus velutinus,* combined with a reduction *Potamothrix hammoniensis* and *Tubifex tubifex* (frequency and abundance) indicated that the oligochaete species structure does not provide a coherent signature of the lake sediment quality.

In contrast to oligochaetes, the bioindicative value of chironomid communities suggested good conditions at the water-sediment interface since 1992 with, in addition,

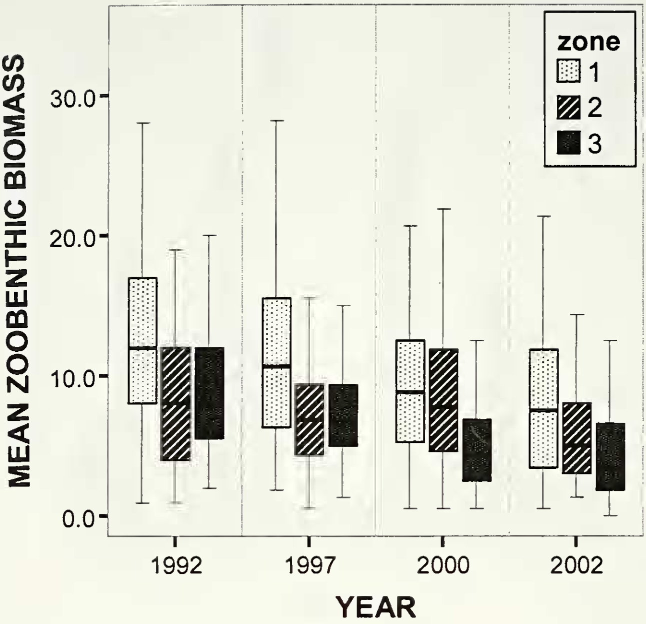

FIG. 4

Mean zoobenthic biomass (oligochaete worms and chironomid larvae) (FW, g m^{-2}) between 1992 and 2002 and between zones. The median, percentiles (25th and 75th) and 1.5 interquartile range are indicated.

TABLE 4. Summary of the analysis of variance (one-way ANOVA) inter-zones for two variables.

Variable		ANOVA inter-zone	
		F	*P*
Black reduced layer	1997	7.99	*< 0.001*
	2000	38.24	*< 0.001*
	2002	30.80	*< 0.001*
Zoobenthic mean biomass	1992	5.33	*0.006*
	1997	10.52	*< 0.001*
	2000	15.49	*< 0.001*
	2002	4.46	*0.013*

the presence and the settlement of *Paracladopelma nigritula* gr., a species group characteristic of oligotrophic lakes (Saether, 1979). This taxon was also present in Lake Geneva at a depth of 40 m in 1995 (Lods-Crozet, unpubl. data) and in Lake Annecy (Verneaux & Verneaux, 2002). Chironomid composition and richness (11 taxa) during the last ten years is analogous to that of other lakes of the Alpine region, for the same depth: Lake Constance (Reiss, 1968), Lake Geneva (Lods-Crozet & Lachavanne, 1994) and Lake Starnberger (Gerstmeier, 1989). Furthermore, the inter-annual up and down pattern (Fig. 5) could be explained by the fact that, if profundal communities are food limited, then year-to-year fluctuations in autochtonous algal production may ulti-

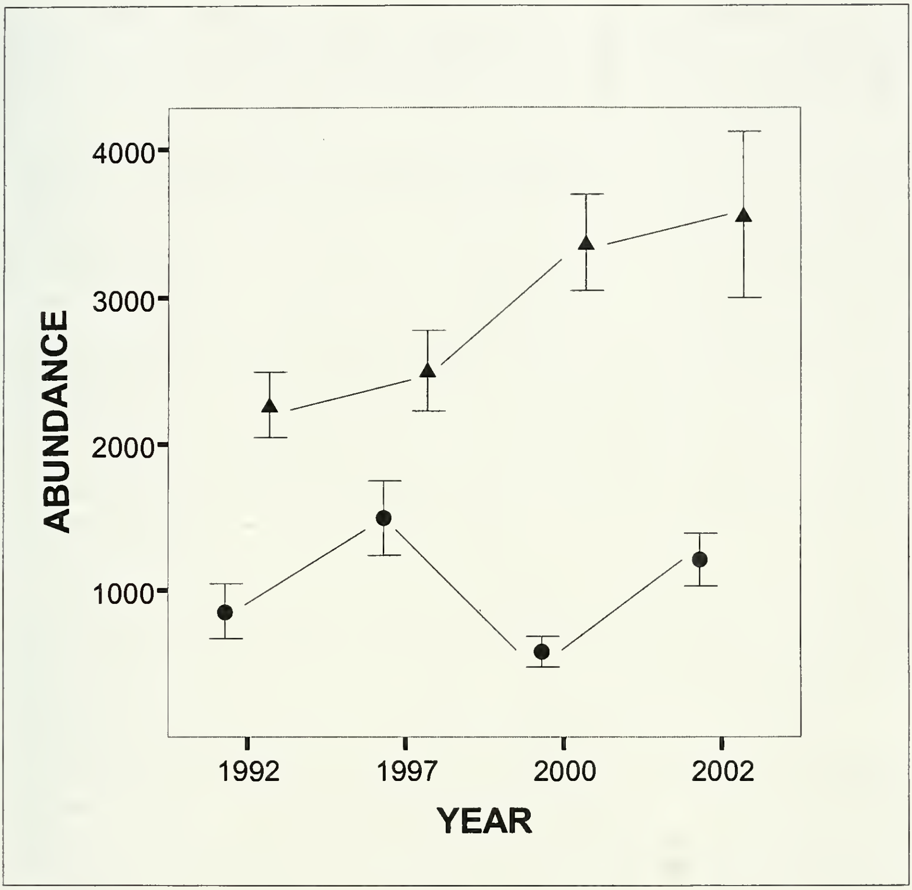

FIG. 5

Total abundance (No. m^{-2}) of oligochaete worms (circles) and chironomid larvae (triangles) (± CL) between 1992 and 2002.

mately affect profundal zoobenthos communities resulting in time-delayed population responses (Johnson & Wiederholm, 1992).

In addition, two species of molluscs (*Pisidium conventus, P. personatum*), typical of deep lakes were found. These two species were also present in the deep zone of the oligotrophic Lake Annecy, France (Mouthon, 2002) and were rare or absent in meso-eutrophic Swiss lakes (P. Stucki, pers. comm.)

THE EFFECTS OF ABIOTIC AND BIOTIC FACTORS

Chemical and phytoplanktonic metrics in the pelagic waters of lake Neuchâtel indicate that mean total phosphorus concentrations in the water column have markedly decreased from 38 mg m^{-3} in 1984 to 18 mg m^{-3} in 1992 and 10.0 mg m^{-3} in 2002. Consequently, mean algal biomass has also decreased (Pokorni-Aebi, 1997, 2002). In contrast, during a similar phase of recovery from eutrophication in Lake Geneva, good relationships were found between pelagic chemical parameters and zoobenthic communities, with a significant increase of oligochaete species bioindicators of oligotrophic conditions (Lang, 1998).

In order to understand these divergent trends between zoobenthic groups we have explored three main hypotheses. One of them is contamination of sediment by micropollutants (heavy metals, PCBs and PAHs) and their potential impact on zoobenthic communities. Anthropogenic contaminants were detected along the 15 kilometres-long transect, but no spatial differences were noted. Heavy metals concentrations were relatively low compared to those measured in Lake Geneva in 1983 (Mondain-Monval *et al.*, 1983) and in 2003 at 70 m-depth in the same lake (Lods-Crozet, unpublished data). Compared to background concentrations observed prior to industrialisation (Vernet & Viel, 1984) mean values were close and even lower than background levels (Table 4). PCBs in Lake Neuchâtel have similar values as at 70 m-depth in Lake Geneva (Lods-Crozet, 2003, unpublished data). Their long-term persistence in the upper layer of bottom sediments, despite their banning in industrial processes since 1986, could explain the residual contamination. PAHs levels are higher than those measured at 70 m depth in Lake Geneva: 0.193 mg Kg^{-1} (Lods-Crozet, 2003, unpublished data). The Swiss reference is a zero value for these synthetic and persistant contaminants (PCBs and PAHs) but reasonable limits could be chosen on the basis of threshold values determined for agricultural valorisation of wastewater sludges (Osol, 1998) (Table 2).

Similar levels of sediment contamination by heavy metals and PAHs were found in Lake St-François, Canada (Pinel-Alloul *et al.*, 1996) and attempts to correlate contaminants and macroinvertebrate metrics were unsuccessful. It should be stressed that sediment toxicity assessment is not an easy task (Luoma & Carter, 1993) and sediment quality criteria essentially take into account the capacity of benthic organisms to tolerate the different contaminant concentrations. Substantial doubt exists about pollutants concentrations that pose significant ecological dangers because the bioavailable fraction of toxicants in sediments is rarely measured (Pardos *et al.*, 2004). The use of sediment quality assessment metrics, developped by Smith *et al.* (1996) permitted the following considerations. The Probable Effect Level (PEL) on benthic organisms, showed that the concentrations of metallic and organic (PAHs) contaminants detected were well below those estimated by the PEL (Smith *et al.*, 1996). On the other hand, in laboratory experiments, Nalepa (1991) pointed out that sublethal effects were apparent at lower concentrations than those reported from Lake Ontario sediments. For instance, *Stylodrilus heringianus* ceased feeding after 58 days at PCB concentrations over 0.05 mg Kg^{-1} (PCB congeners not known). Concentrations at this level were found in Lake Neuchâtel in 2003. In addition, tubicifids feed continuously in a conveyor-belt fashion by ingesting particles in bulk at depth and defecating on the sediment surface. Such bioturbation has been reported to significantly increase the flux of metals and organic contaminants from sediment into the water column (Reynoldson, 1987; Reible *et al.*, 1996). While results of laboratory experiments may not be applicable to the field situation, these results do demonstrate the possibility of low-level, long-term chronic impacts of pollutants on oligochaete populations (Nalepa, 1991).

Another hypothesis, proposed by Lang (1999) was the changes in the phytoplankton composition between 1993 and 1996, with the dominance of large diatoms (Butty *et al.*, 2003). These have a high sinking rate and as a result, sedimented intact on the bottom surface. Algal signatures at the sediment level were also observed by Steinmann *et al.* (2003) using the analysis of suspended material from the lake epilimnion. Settlement of these algae is known to increase oxygen uptake at the water-sediment interface (Johnson *et al.*, 1989; Lang, 1999). Consequently, some oligochaete species, sensitive to oxygen depletion, were able to be disturbed in their growth and reproductive behavior.

The last hypothesis concerned competition mechanisms. Few studies have actually demonstrated increases or decreases in population growth rate by interaction between oligochaete species (Milbrink, 1993; Timm, 1996). The rapid expansion of Ponto-Caspian *Potamothrix vejdovskyi,* which may compete for habitat and food with other oligochaete species like *Stylodrilus heringianus* and *Embolocephalus velutinus,* should not to be neglected. Furthermore, increase of lake water temperature during the last fifteen decades (Lazzarotto *et al.*, 2002; Pokorni-Aebi, 2002) may have enhance growth and reproduction of this opportunistic species and strengthened up its expansion over more stenothermic native species.

Our study confirms the potential multiple controls of the macroinvertebrate community in anthropogenically stressed ecosystems by both simple and combined effects of chemical, toxicological, biological and ecological factors. Further improvement of lake biomonitoring programs must address assessment of the structure of predominant and profundal zoobenthic community (oligochaetes, chironomids and bivalves molluscs). We consider that Lake Neuchâtel, in terms of biological quality of sediments is in phase of recovery from eutrophication, by using zoobenthic biomass, chironomid community structure and *Pisidium* assemblages as descriptors. The decline of characteristic oligochaete species indicators of oligotrophic conditions from 1992 should be monitored further in order to better understand the causes of this apparent degradation.

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